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FURTHER SILO STUDIES 1/

By J. R. McCalmont, Asst. Agr. Engr., Bureau of Agricultural Chemistry and Engineering, U.S. Dept. of Agri., to be presented before the annual meeting of the National Association of Silo Manufacturers, at Chicago, December 1, 1941

The past 8 years have witnessed a change in farm practices that has resulted in the use of many crops, other than corn, for silage. Several factors have had a part in causing this change; some of the more important ones are the difficulty in putting up hay and other dry forages in wet seasons, the high cost of raising corn in some localities, the effort to keep summer-milk quality the year round and the increased use of soil-saving crops. The call to the American dairy farmer to increase milk production as a defense measure during the coming year will demand additional silage. Much of this increase will be "grass silage," by which is meant silage from grasses, legumes, and cereal grains either with or without added preservative. The desire to get a feed high in carotin and protein has led to storing crops at an early stage of maturity when the moisture content is high. High moisture contents along with preservative and the packing characteristics of such plants lead to high pressures, leakage, and the attendant higher corrosion rate on many of the materials used in silo construction. These effects are more general in silos filled with grass silage but are also present when silos are filled with high-moisture corn silage.

During the past 6 years while the Cooperative Silo Project has been under way at the Dairy Research Farm of the New Jersey Agricultural Experiment Station and the Beltsville Research Center of the U. S. Department of Agriculture, pressures, density, drainage, and the protection of silo walls have been studied. Pressures have been measured in silos filled with corn silage ranging from 68 to 81 percent moisture and with grass silage ranging from 62 to 78 percent moisture. The horizontal pressures, at a 40-foot depth, with corn silage ranged from 310 pounds per square foot in a 14-foot-diameter silo to 900 pounds in a 16-foot silo; with grass silage the range was from 280 pounds in a 12-foot silo to 1,167 pounds in an 18-foot silo. It is interesting to note that the highest moisture content was found in corn silage while the highest pressure was recorded with grass silage.

1/ Cooperative silo studies have been carried on at the Beltsville Research Center of the U. S. Department of Agriculture since 1936 and at the Dairy Research Farm of the New Jersey State Agricultural Experiment Station since 1937. The work at the New Jersey Station has been under the direction of Dr. J. W. Bartlett of the Department of Dairy Industry and Prof. W. C. Krueger of the Dept. of Agricultural Engineering. D. . Friend is the graduate student who is carrying on the work at the farm.

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A summary of our tests shows that silo pressures increase with moisture content of the silage and diameter of the silo for both corn and grass silage; but with equal moisture contents and diameters, grass silage gives greater pressures because of closer packing or higher density. The growing practice of putting-up grass silage without wilting, using material as delivered by the silage field harvester or grass combine, contributes to high silo pressures. The general increase in the use of grass silage and the use of unwilted material mean that more high-moisture grass silage will be put up and more silos will have to withstand high pressures.

The pressures measured during the past season showed no change from the maximum or minimum pressures measured in former years for silos of equal diameter, since the moisture contents have been between the same maximum and minimum limits. However, with the additional data we have been able to construct curves showing the increase in pressure in silos with increasing diameter but constant moisture content of silage, and additional curves showing the pressure-increasing effect of increasing moisture content of silage in silos of constant diameter. Figure 1 shows the horizontal pressures at the bottom of silos 12, 14, and 18 feet in diameter from grass silage containing 70 percent moisture as the depth of silage increased to 40 feet. Figures 2, 3, 4, and 5 give the horizontal pressures in silos 12, 14, 16 and 18 feet in diameter from various types of silage having different moisture contents. The kind of material, the preservative used, and the speed of filling have some effect on the pressures, but from these curves it is quite evident that moisture content is the chief controlling factor. Analysis of the data from 26 silos has given formulas which have been used for constructing curves to show the maximum horizontal pressures that must be provided for in the design of silos.

Figures 6 and 7 present design curves for large and medium-sized silos and for silage of usual and high moisture contents. There is such a great difference between the pressures actually measured in large silos and the pressures actually measured in medium-sized silos that two sets of formulas are required. This change must be attributed to the arching action of the silage and its angle of repose. In figure 6 the formula,

$P_h = \frac{dh^{1.13}}{h^{1/h}}$ (where P_h the horizontal pressure, d the diameter and h the depth of silage) gives a curve that agrees very well with the average measured pressures in silos 12 to 14 feet in diameter filled with silage containing 75 percent or more of moisture. In figure 7 the curve constructed from the formula $P_h = \frac{dh^{1.56}}{5}$ represents the pressures in silos 16 to 18 feet in diameter filled with silage containing 75 percent or more of moisture. The formula $P_h = \frac{dh^{1.9}}{2.65h^{1/1.42}}$ for pressures in silos 12 to 14 feet in diameter and

$P_h = \frac{dh^{1.45}}{5}$ for these in silos 16 to 18 feet

in diameter, used to draw the corresponding curves shown in Figures 6 and 7, and were calculated from the average pressures measured in silos filled with silage having moisture contents up to and including 74 percent. The curves show considerably lower pressures than were observed with high-moisture silage, but would be considered adequate for silage of all moisture contents if the silo were equipped with an effective drainage system to remove the excess moisture from the silo. If silos designed for moisture contents up to 74 percent are not equipped with drains and are filled with high-moisture silage leakage will occur and parts of the structure will be attacked by the silage juices. To some extent the conditions would be the same as have been observed in the past in silos built for corn silage. The silos, when filled with normal corn silage, were adequate and there was no leakage; but when a late-maturing crop or early frost caused the silage to be put up with a high-moisture content the silo leaked and the pressures were probably high enough to reduce the factor of safety in the reinforcing steel from 3 to 2. Since this high-moisture silage was put up only once in 5 to 10 years the bad effect on the silo was not noticeable until it was very old. However, with grass silage there are possibilities of having silage of 75 percent or more moisture in most years and thus the bad effects of high moisture and leakage will be multiplied and will make necessary more reinforcing, along with effective drains if the silo is to function under all moisture conditions.

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It was thought that pre-stressing of reinforcing hoops would help to reduce the amount of leakage from the joints between staves in silo walls, and in former years the hoops on two silos were drawn up to give a tension of approximately 18,000 pounds per square inch. This should allow for the pressures on the walls, and not give sufficient elongation in the hoops to open cracks between the silo staves. Such tests reported last year gave some indication of being successful. Additional tests of pre-stressing the hoops of concrete-stave silos have been made in which it was found that most of the leakage from the vertical joints could be stopped but leakage would still occur through the horizontal joints. These trials showed that it is practically impossible to get a uniform stress in silo hoops due to friction between the walls and the hoops. The stress is always greatest near the ends where the hoops are tightened. It is indicated that, once the hoops on a concrete-stave silo have been tightened and all joints between staves have been seated, the stress in the hoops does not decline much. The greatest changes in the hoop stress are due to the shrinking and swelling of the concrete as it loses or takes up moisture, and variations in pressure as the silo is filled or emptied and as the silage freezes and thaws. The effects of these separate factors on hoop stress cannot be reported until special tests have been made under various experimental conditions.

Since excessive leakage around silo doors and through the walls of silos has an injurious effect on materials of silo construction and causes offensive odors, it is important to control leakage either by reducing the original moisture content of the silage or by carrying the liquid off in drains. Two years ago 3 foundation-wall drains were placed in each of two silos 18 feet in diameter. These drains functioned very

well when the silos were filled with silage containing 68 percent moisture, but when the silos were filled with silage containing 76,77, or 78 percent moisture only a small part of the excess juice was carried off by the drains, the remainder coming through the doorway and the joints in the walls. Similar foundation-wall drains in a silo 14 feet in diameter were connected to 3 vertical drains next to the inside wall of the silo. Two of the vertical drains were made up of "horseshoe" tiles set end to end in the silo as filling progressed; the third consisted of vitrified "bell" tiles each having a half-inch hole throughout its length, placed in the same manner. When this silo was filled with silage containing 71 percent moisture less than 1 percent of the juice was drained from the silo, all of which came from the drains made of horseshoe tile. Further tests on these and other types of vertical wall drains should be conducted with high-moisture silage. Table 1 lists the kinds of silage placed in the various silos equipped with drains, and the percentage and amount of juice drained from each.

Table 2 gives the type and weight of green material placed in the various silos along with the percent of moisture and the weight of dry matter in the silage. The weight of dry matter in silos filled with high-moisture silage is small compared with the weight of the green material placed in them.

Figure 8 shows the densities of silage as fed out of six silos. The effect of diameter of silo on the density of silage is quite noticeable. The average density of silage in silos of the same diameter is about the same for different moisture contents; low-moisture silage will have a slightly greater density than high-moisture silage for depths over 15 feet and the reverse will be true for depths under 15 feet. Densities measured by means of floats placed in the silo, showing the space occupied by different weights of silage, are always somewhat higher than densities calculated from weights of measured volumes of silage when fed, due to expansion of the silage when not under pressure from above. However, such figures are likely to be misleading when any drainage has occurred because the loss of weight from drainage cannot be assigned to a particular part of the silo.

The presence of weak acids in silage juices has always presented the problem of protecting the inside walls of silos. The increased use of grass silage increases the seriousness of this problem because in general grass silage is put up with a higher moisture content. This makes it yield more juice and at the same time higher pressures which tend to open more cracks in the walls. The protection of inside walls in masonry silos (plastered or finished with a brush coat of neat cement) with paint coatings has proved difficult since the coatings will not bond well to the surface or penetrate it. Twenty-four different coatings have been applied to silos at the New Jersey Station. None of the coatings has been tested for a long enough period to give any positive results. The best results noted so far have been given by a phenolic resin-tung oil varnish.

Since many of the coatings applied in the old silos broke down through bond failure rather than acid action it was decided to try some of them on a new concrete-stave silo in which the inside walls had never been plastered or covered with a cement wash. Twenty-one coatings were applied to a new silo of this kind on the Ayres farm in Sussex County, New Jersey, early last summer. These were given preliminary inspection before the silo was filled and after the silage had settled a few feet. While no positive results can be given now it was found that 7 coatings were unsuitable. Of the remainder two phenolic-resin varnishes appear to be the best. Of 6 different coatings tested on a new metal silo only one, an asphaltic paint having a high melting point, shows any promise for coating steel silos. A supplemental report will be prepared when the silos are empty, giving condition of the coatings after from 1 to 3 years exposure to silage action.

SUMMARY

Our tests showed that the diameter of the silo and the moisture content of the silage greatly affect the horizontal pressures on silo walls; a material increase in pressure results when the diameter is increased from 14 feet or less to 16 feet or more, and also when the moisture content changes from 74 percent or less to 75 percent or more.

The formulas $P_h = \frac{dh^{1.9}}{2.65h^{1/1.42}}$ (for medium-sized silos and $P_h = \frac{dh^{1.45}}{.5}$ (for large silos) will give the maximum horizontal pressures to be considered in silo design, if adequate drainage is provided to remove the excess moisture.

Foundation-wall drains are effective for low-moisture silage.

Vertical wall drains made up of "horseshoe" tiles have shown indication of being effective with silage containing 71 percent moisture but will have to be tested further with high-moisture silage.

Lifetime-durable coatings for concrete silos are still unknown. Phenolic-resin varnishes, bitumens, and cement washes show promise of giving protection for several years. All coatings should be applied early enough to give time for thorough drying before the silo is filled. Bitumen preparations show the most promise for coating steel silos.

When a bituminous preparation is used, one having a high melting point should be selected to minimize the danger of silage sticking to it.

Especial care must be taken to protect the reinforcing metal in masonry-unit silos where the reinforcing cannot be inspected.

The dry-matter content of silos is approximately the same for corn and grass silage of the same moisture content, other factors being the same.

Table 1. - The Material Percent Moisture and Amount of Drainage or Leakage from 9 Silos

Silo	Year	Material	Preservative	Tonnage	Moisture	Leakage & Drainage	
					Percent	Gallon	
B.E.4	1939	Alfalfa & clover	Acid	188	68	3,990	9
B.E.5	1939	do do	Molasses	198	68	975	2.24
B.E.4	1940	Alfalfa	Acid	333	77	12,390	16
B.E.5	1940	do	Molasses	318	77	12,860	18
B.E.6	1940	do	Phos. acid	97	70	225	1
B.E.4	1941	do	Acid	207	76	6,429	14
B.E.5	1941	do	Molasses	209	78	7,318	15
B.E.6	1941	Oats & peas	Phos. acid	105	74	Trace	Trace
B.E.8	1941	do do	Molasses	131	71	do	do

Table 2. - Size of the Silos Tested, Type of Silage with its Moisture and Dry Matter Content

Silo No.	Silo Diameter	Depth of silage	Total tons in silo	Average moisture content	Tons in dry matter	Material in silo	Preservative
	Feet	Feet		Percent			
B-9	11.6	30.0	80	71	23	Alfalfa & mixed grasses	Molasses
B-6	12	25.0	49	64	18	Alfalfa & oats	Molasses & silo germ
B-6	12	40.0	159	78	35	Alfalfa & clover	Molasses
B-6	12	40.0	97	70	29	Alfalfa	Phos. acid
B-6	12	40.0	105	74	28	Oats & peas	do do
S.C.	14	32.5	91	62	35	Alfalfa	None
S.C.	14	44.0	106	66	36	Cereals	do
B-8	14	42.0	141	71	41	Alfalfa	Molasses
L-5	14.3	35.0	115	74	30	Oats & peas	Oathulls & 40% molasses
B-8	14	39.0	131	71	39	Oats & peas	Molasses
B-2	18	41.0	264	74	69	Corn	None
B-5	18	31.5	198	68	63	Alfalfa & clover	Molasses
B-4	18	32.5	188	68	60	do do	Phos. acid
B-5	18	40.0	333	77	77	Alfalfa	do do
B-4	18	40.0	318	77	73	do	Molasses
B-2	18	42.5	268	72	75	Oats & peas	do
B-5	18	26.5	207	76	50	Alfalfa	Phos. acid
B-4	18	26.5	209	78	46	do	Molasses
S.C.	14	42.0	126	71	37	Corn	None
S.C.	14	43.0	149	69	46	do	do
S.C.	14	43.5	151	70	45	do	do
S.C.	14	44.5	149	72	42	do	do
B-7	16	37.5	198	74	51	do	do
B-7	16	40.5	209	81	40	do	do
B-2	18	21.0	127	74	33	do	do
B-3	18	18.0	88	72	25	do	do

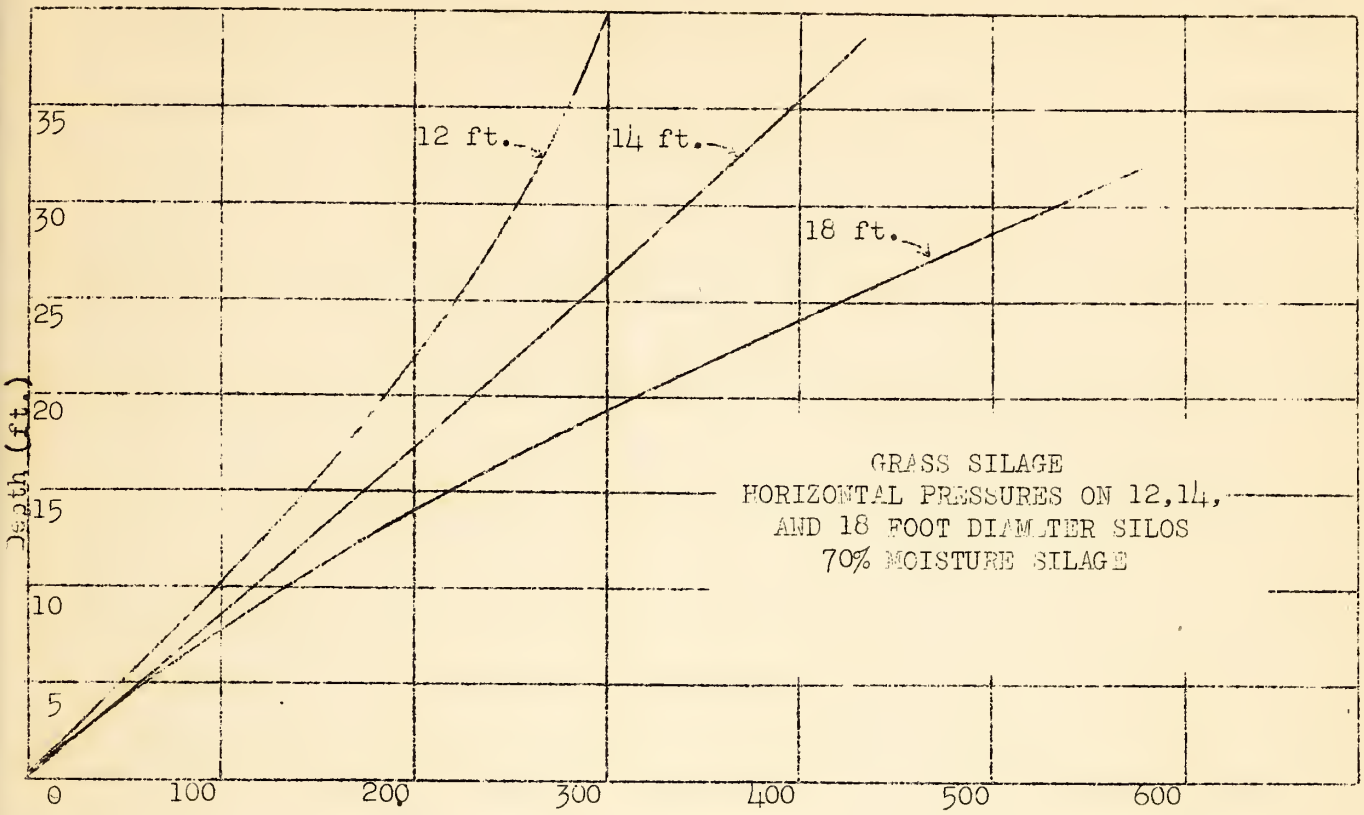

FIG. 1

Horizontal Pressure (pounds per sq. ft.)

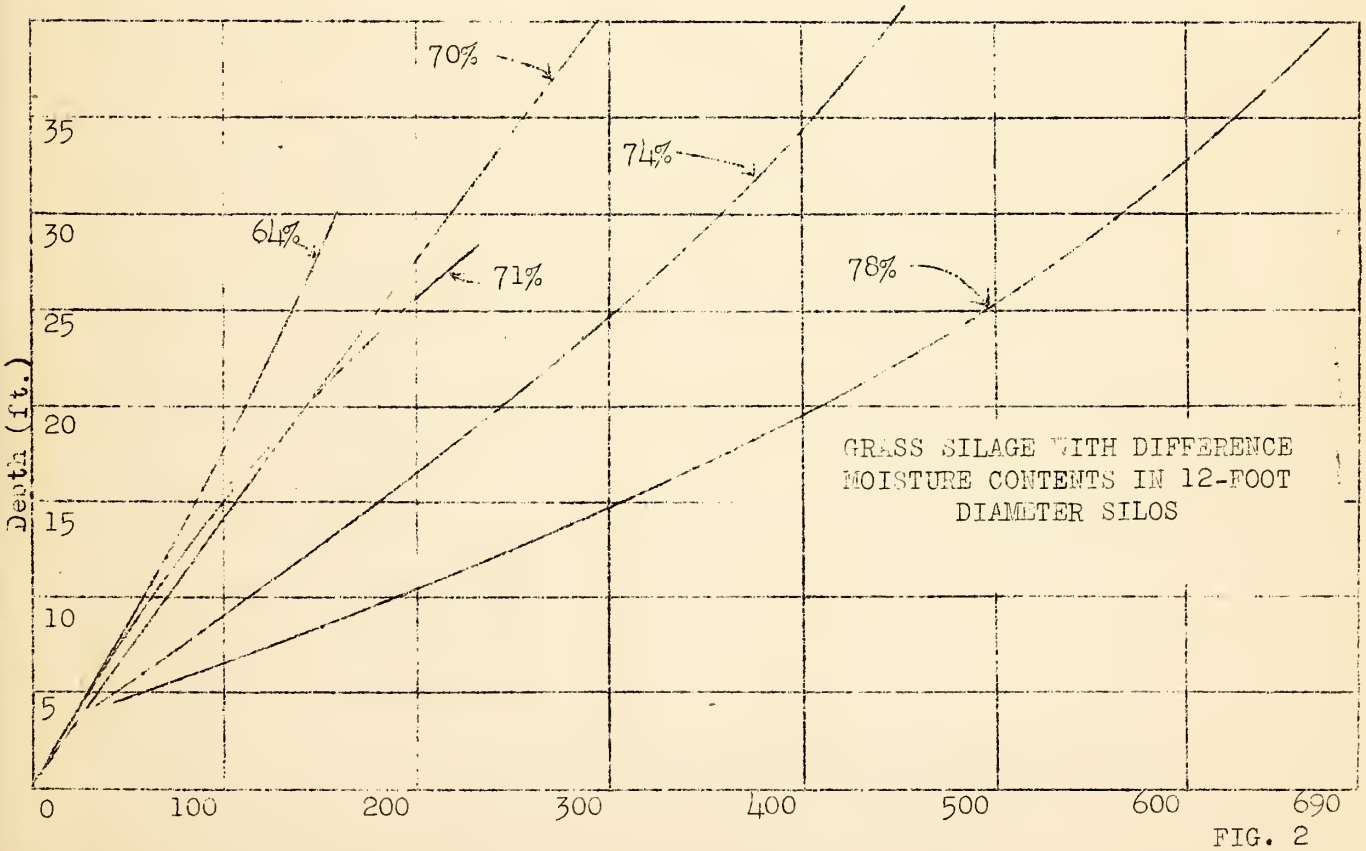

FIG. 2

Horizontal pressure (pounds per sq.ft.)

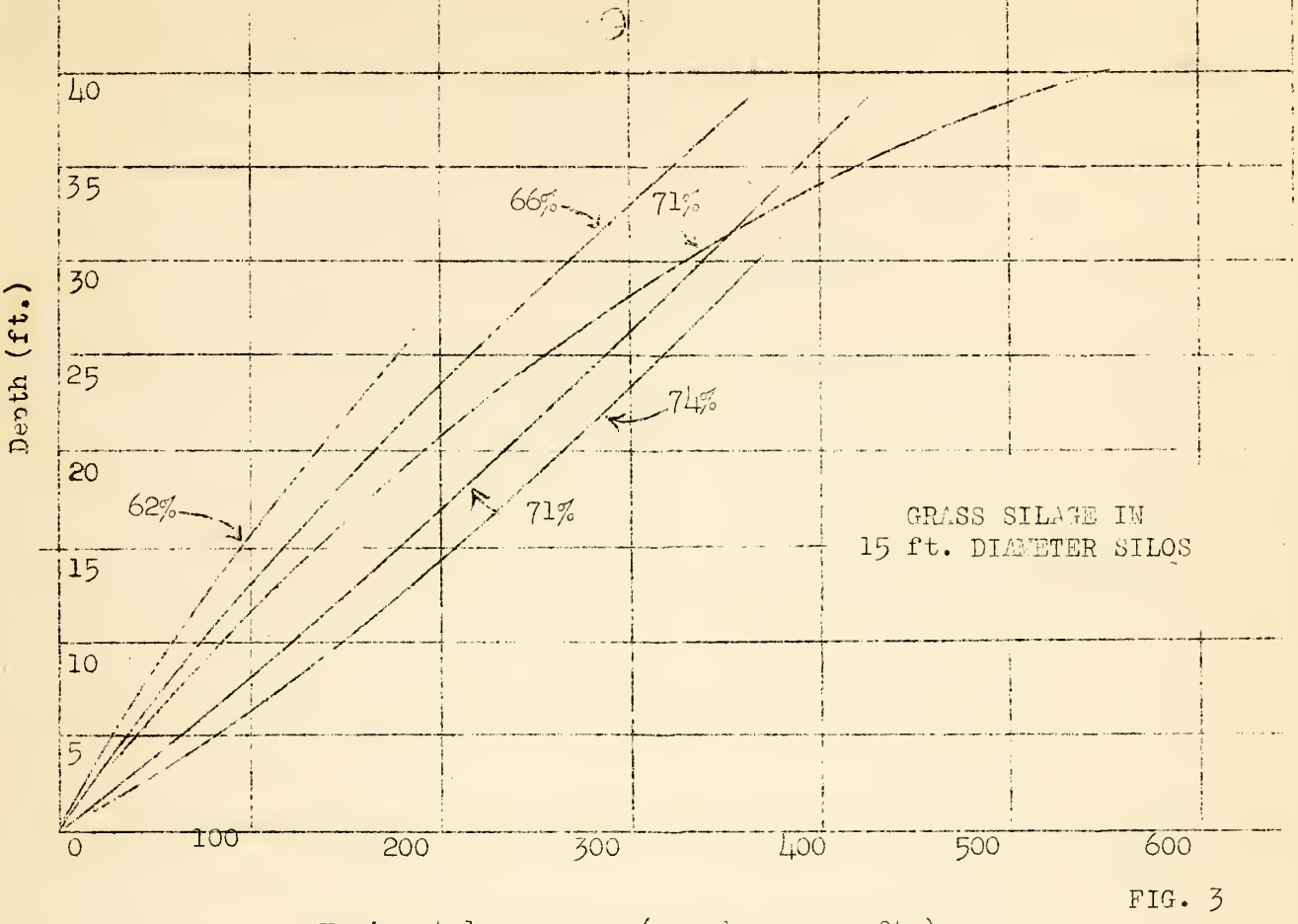

FIG. 3

Horizontal pressure (pounds per sq.ft.)

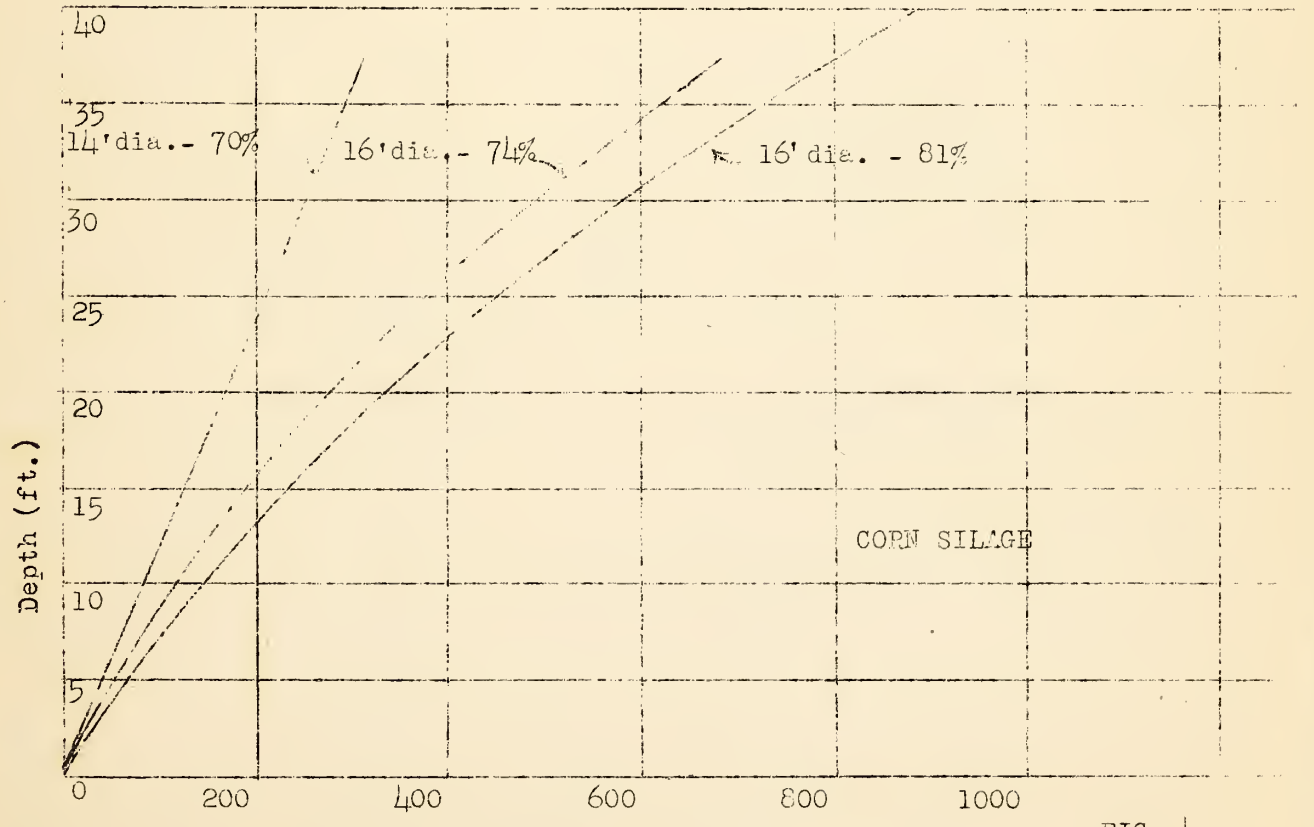

FIG. 4

Horizontal pressure (pounds per sq.ft.)

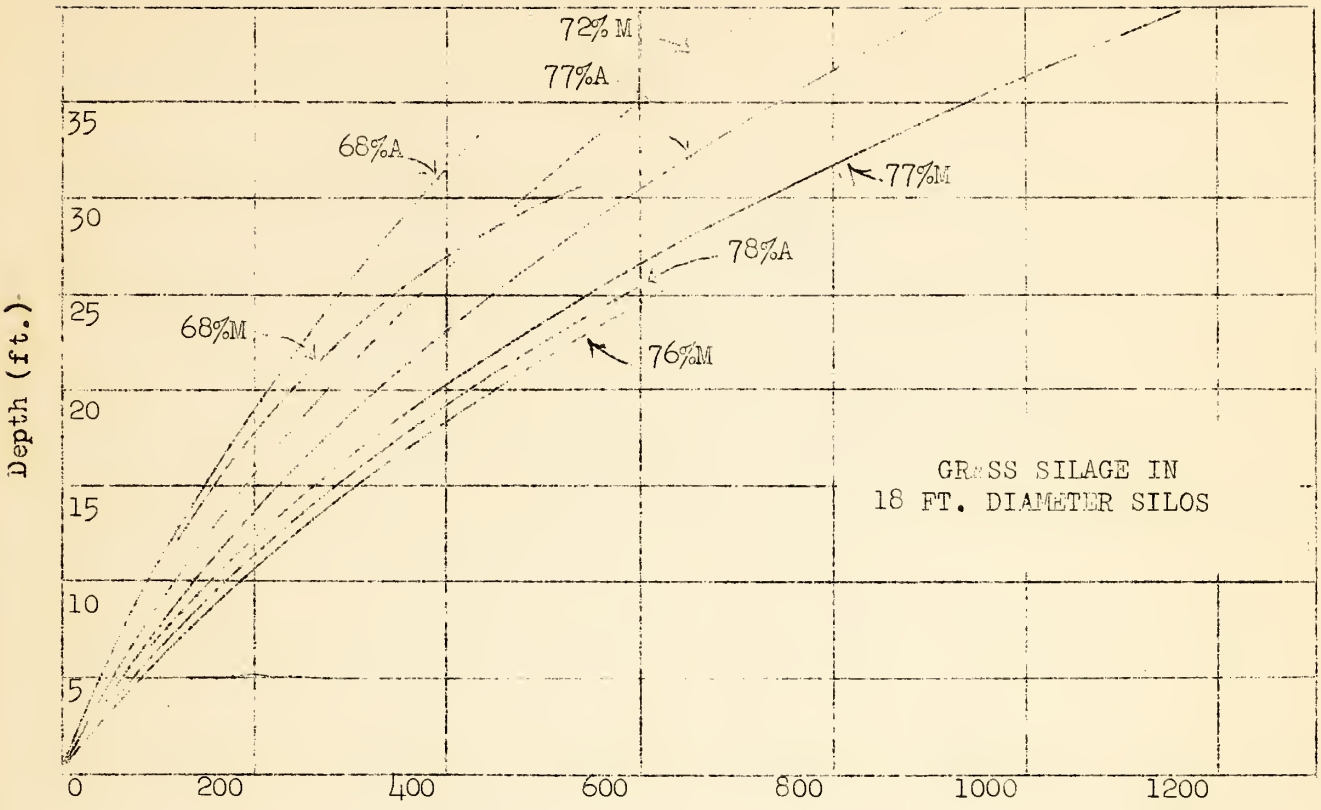
72% M
77%A
68%A
77%M
78%A
68%M
76%M
GRASS SILAGE IN
18 FT. DIAMETER SILOS
Depth (ft.)
35
30
25
20
15
10
5
0
200
400
600
800
1000
1200
Horizontal pressure (pounds per sq.ft.)

FIG. 5

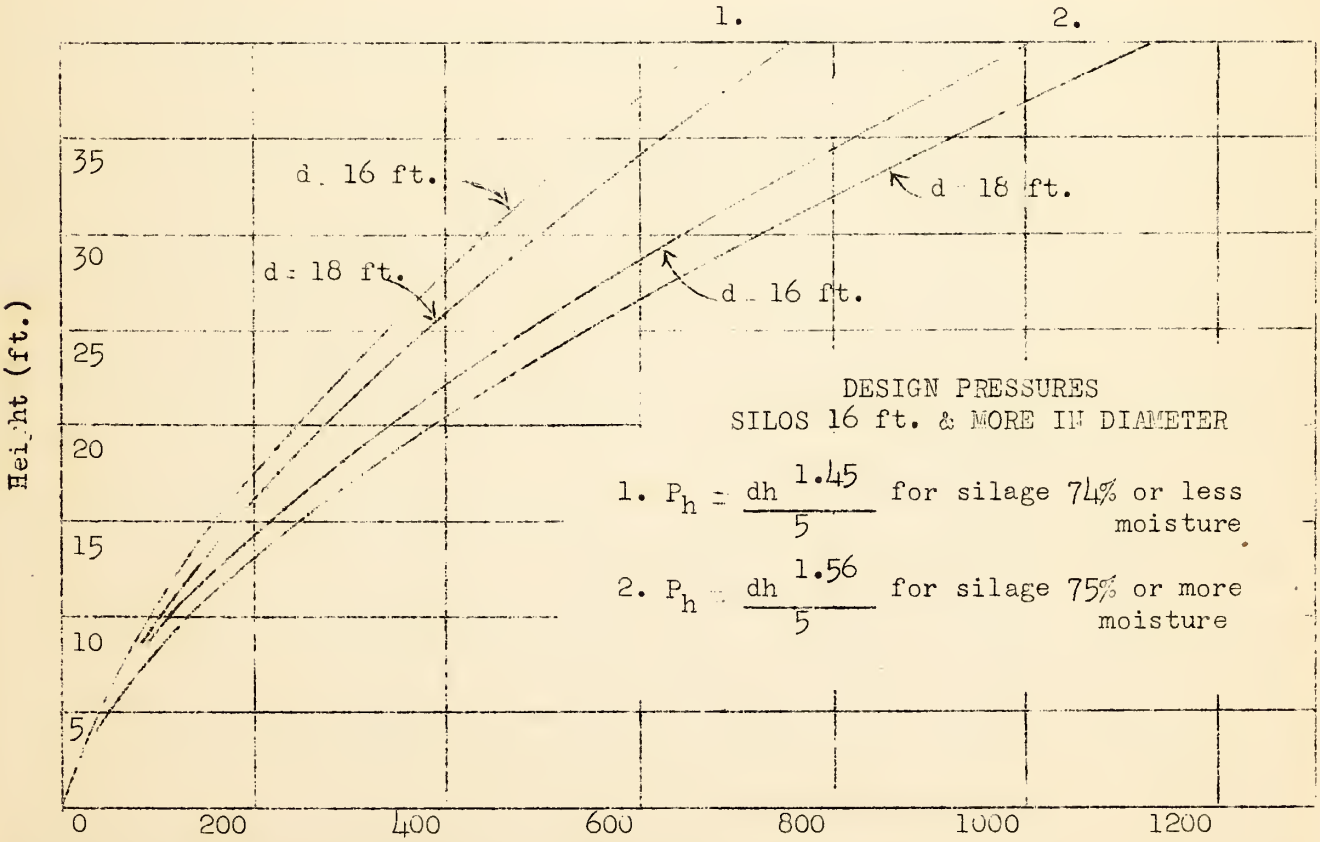
1.
2.
d 16 ft.
d 18 ft.
d = 18 ft.
d 16 ft.
DESIGN PRESSURES
SILOS 16 ft. & MORE IN DIAMETER
1. $P_h = \frac{dh^{1.45}}{5}$ for silage 74% or less moisture
2. $P_h = \frac{dh^{1.56}}{5}$ for silage 75% or more moisture
Height (ft.)
35
30
25
20
15
10
5
0
200
400
600
800
1000
1200
Horizontal Pressure (pounds per sq.ft.)

FIG. 6

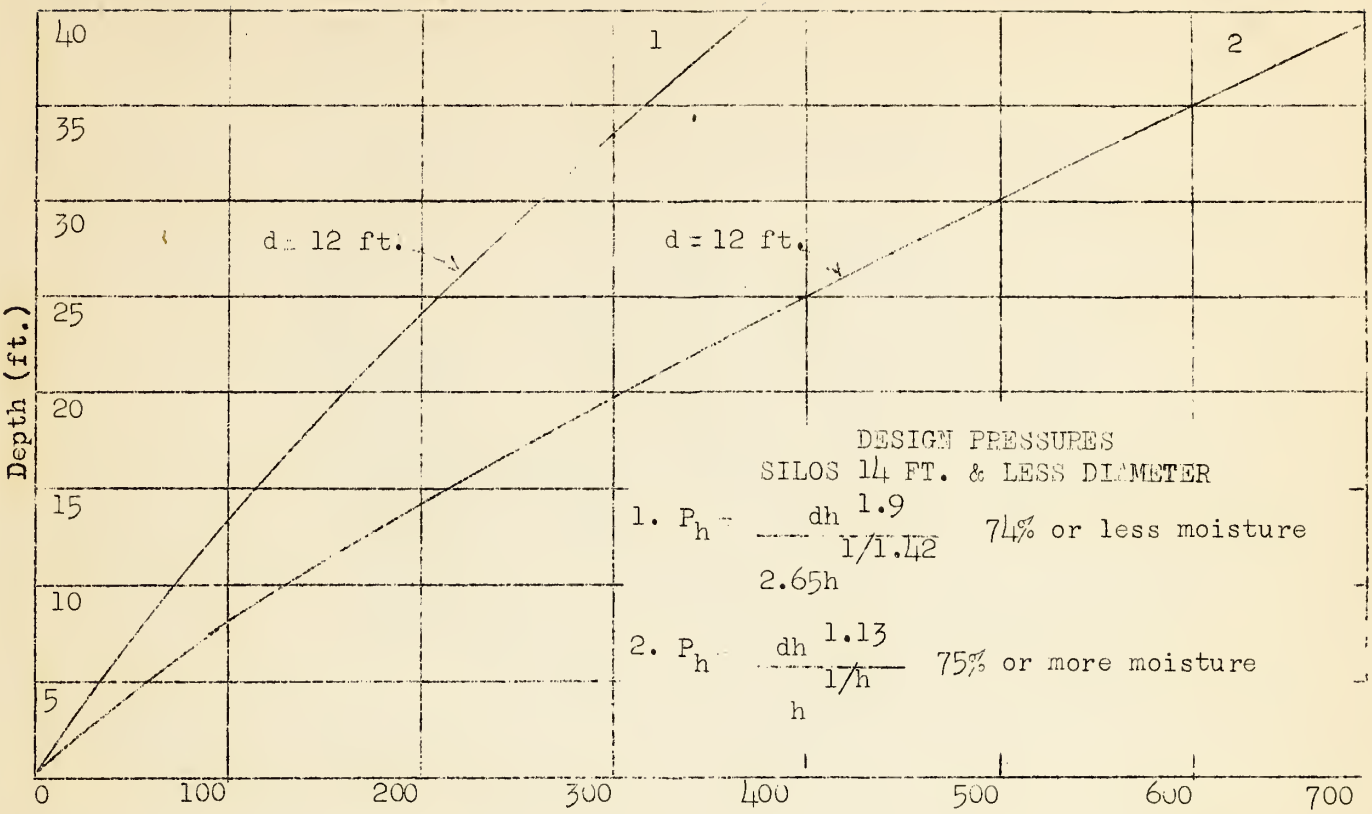
Depth (ft.)
40
35
30
25
20
15
10
5
0
100
200
300
400
500
600
700
1
2
d = 12 ft.
d = 12 ft.
DESIGN PRESSURES
SILOS 14 FT. & LESS DIAMETER
1. $P_h = \frac{dh^{1.9}}{2.65h^{1/1.42}}$ 74% or less moisture
2. $P_h = \frac{dh^{1.13}}{h^{1/h}}$ 75% or more moisture
Horizontal pressure (pound per sq.ft.)

FIG. 7

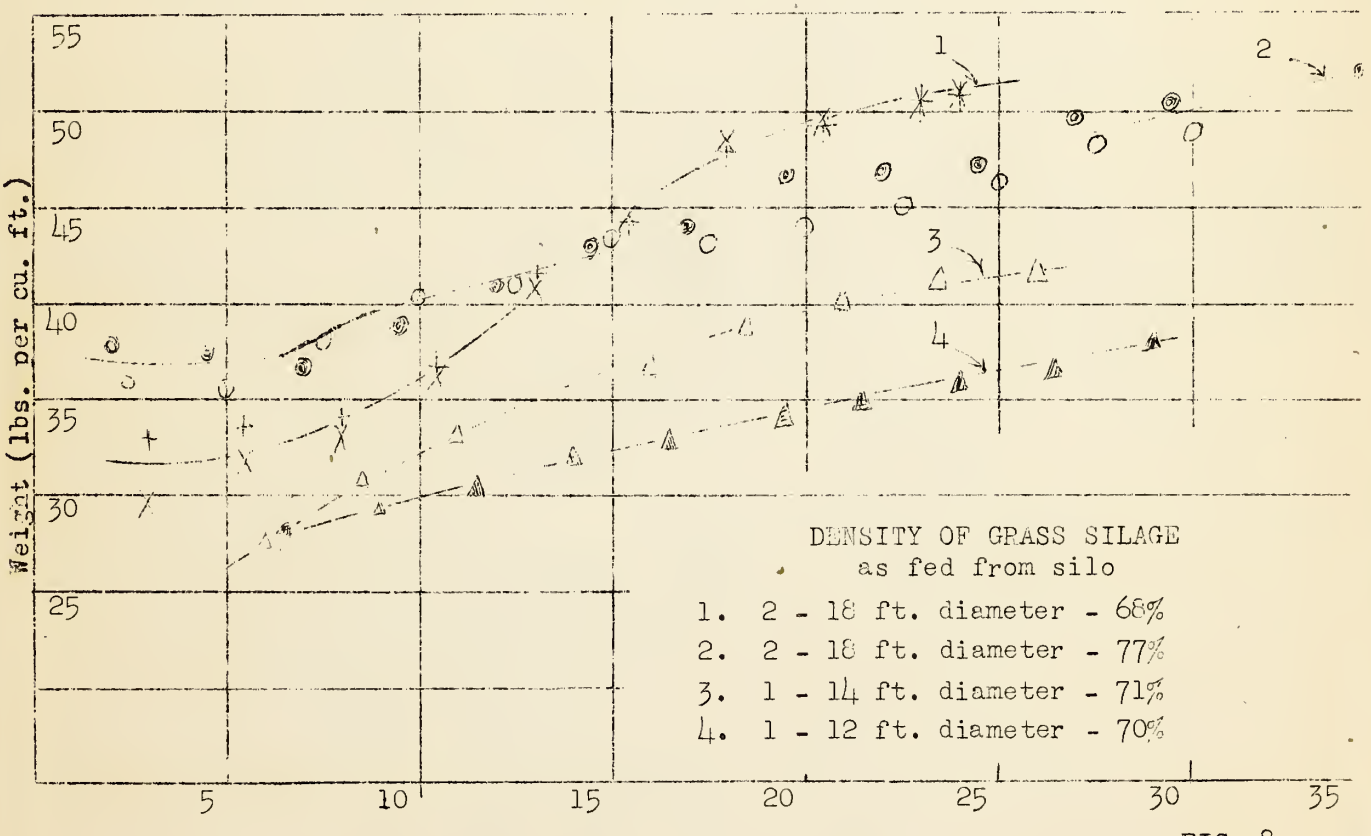
Weight (lbs. per cu. ft.)
55
50
45
40
35
30
25
5
10
15
20
25
30
35
1
2
3
4
DENSITY OF GRASS SILAGE
as fed from silo
1. 2 - 18 ft. diameter - 68%
2. 2 - 18 ft. diameter - 77%
3. 1 - 14 ft. diameter - 71%
4. 1 - 12 ft. diameter - 70%
Depth below surface of settled silage (feet)

FIG. 8